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Performance Based Seismic Analysis and Design of Building Resting on Sloping Ground

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Abstract - *Unavailability of plain ground in mountainous regions necessitated construction of framed building on sloping ground. Buildings situated in hilly areas more seismically vulnerable due to irregular configuration in both horizontal and vertical directions. In present study, two different configuration of G+5 story building with step back and step back set back configuration are modeled in which slope angle is varied. Models are then analyzed for preliminary design by linear static analysis and Response spectrum analysis according to Indian seismic code and evaluated using Performance based Design approach by Nonlinear Static Pushover analysis. This study aims to create awareness about Performance based design approach a method other than conventional prescriptive codes.*

Key Words: Building resting on sloping ground, Performance Based Design, Nonlinear Static Analysis, Response Spectrum Analysis, Step back configuration, Step back set back configuration.

1. INTRODUCTION

The North eastern parts of India have hilly terrain and experiences high seismicity as compared to rest of the country, which are categorized in seismic zone IV and V. Lack of plain land buildings are constructed on sloping ground. Due to economic growth and rapid urbanization there is tremendous increase in population density, housing densities of approximately 62159.2 per Sq Km are around as per 2011 Indian census[1]. Framed structures built on slopes show different dynamic behavior than that on the plain ground, as these are irregular and unsymmetrical in both horizontal and vertical direction. Hence there is a need to study on the seismic safety and design of these structures on slopes. Very few studies have been undertaken in the past to understand the behavior of buildings on hill slopes, where the focus has been mainly on the stability of slopes [2].

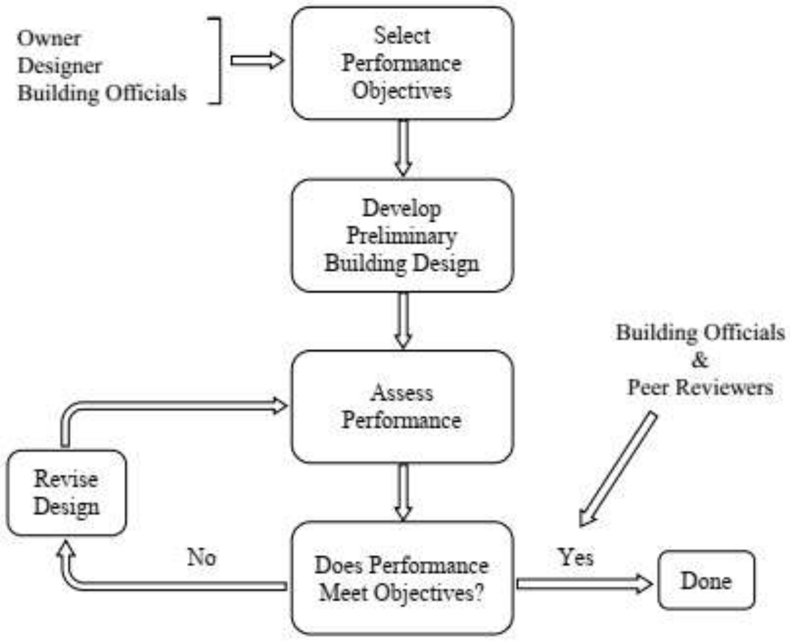


Fig - 1: Performance-Based Flow Diagram (Adopted from FEMA-445, 2006[3])

Linear elastic design techniques for structure fail to directly address structural inelastic seismic responses and thus cannot effectively deal with damage loss due to structural and nonstructural failure during earthquakes. In order to strengthen and resist the buildings for future earthquakes, some procedures have to be adopted. With an aim to communicate the safety-related decisions, the design practice is focused on the predictive method of assessing potential seismic performance, known as performance-based seismic design (PBSD). A simple flow chart for PBSD procedure, which contains the key steps, has been shown in **Fig 1.**

2. Case study

In the present study a G+5 building with two different configurations i.e. Step back and step back set back with varying ground slope 0°, 15°, 25°, 30° are considered. To compare the behavior of regular configuration resting on plain ground a G+5 building having plan same as that of respective hill configuration are considered. Lateral load analysis as per the Indian seismic code [4] for the building resting on flat ground and building resting on sloping ground (step back and Step back Setback [5]), is carried out and an effort is made to study the effect of seismic loads on them and thus assess their seismic vulnerability by performing nonlinear Pushover analysis carried out using Etabs analysis package. Slabs are modelled as rigid diaphragms. Default hinge properties available in ETABS Nonlinear as per ATC- 40[6] are assigned to the frame elements. Building has no walls at all stories and is modelled as bare frame. However masses of the walls are included. In addition to wall masses the other load like floor finish and imposed live load is added at each storey. Three distinct analyses are carried out Equivalent Static Analysis, Response Spectrum Analysis, and Nonlinear Pushover Analysis.

In this study nine models are studied as described below:

Table -1: Model information

Model No.	Type of Structure
1	G+5 Storey building on 0° slope
2	G+5 Storey building on 15° slope with Step back
3	G+5 Storey building on 25° slope with Step back
4	G+5 Storey building on 20° slope with Step back
5	G+5 Storey building on 30° slope with Step back
6	G+5 Storey building on 15° slope with Step back and Setback
7	G+5 Storey building on 20° slope with Step back and Setback
8	G+5 Storey building on 25° slope with Step back and Setback
9	G+5 Storey building on 30° slope with Step back and Setback

The plan layout and elevation of the reinforced concrete moment resisting frame of five storey building is shown in **Fig - 2** to **Fig - 11** respectively. In this study, the plan layout is deliberately kept same to study the effect of step backs.

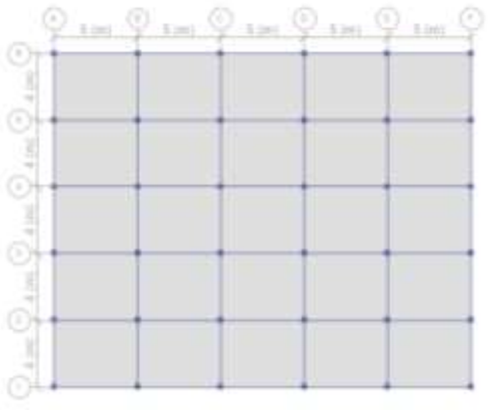


Fig - 2: Typical Plan

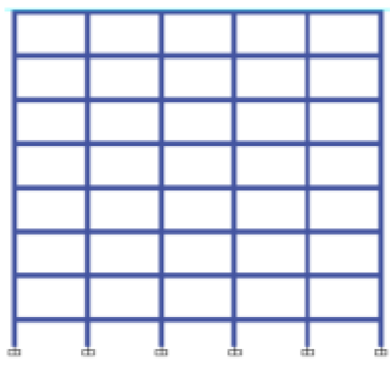


Fig - 3: Model 1

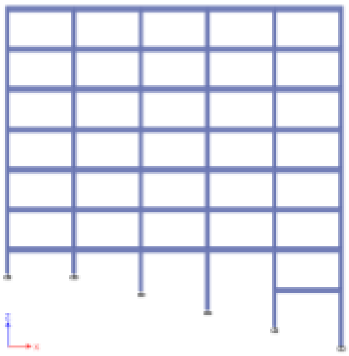


Fig - 4: Model 2

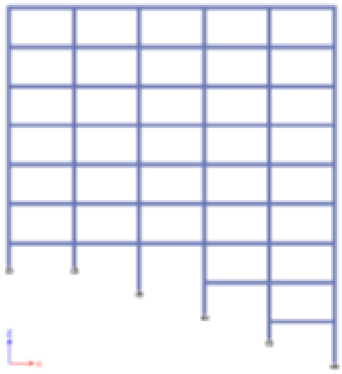


Fig - 5: Model 3

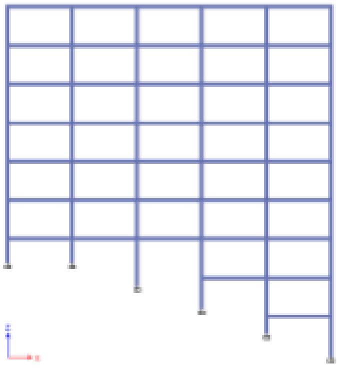


Fig - 6: Model 4

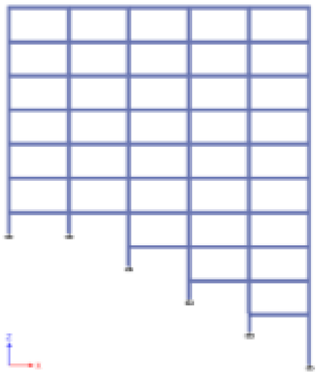


Fig - 7: Model 5

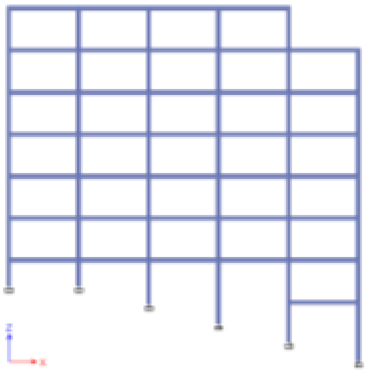


Fig - 8: Model 6

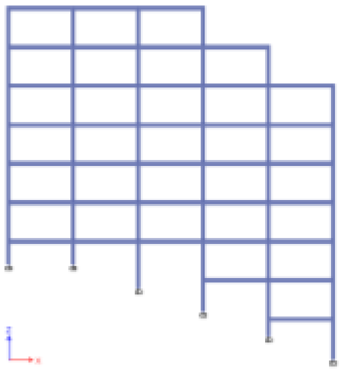


Fig - 9: Model 7

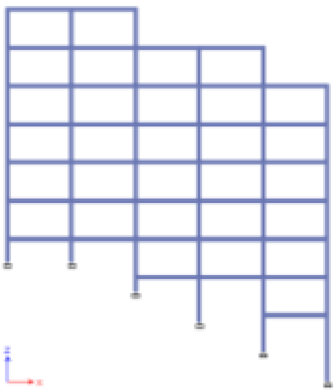


Fig - 10: Model 8

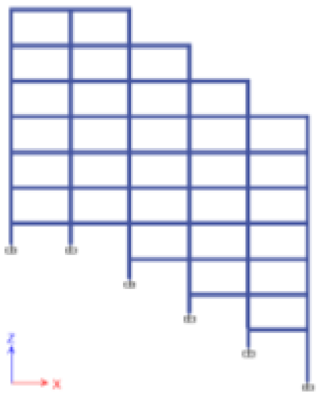


Fig - 11: Model 9

The input data given for the buildings is detailed below.

Example description

Number of storey	: 05
Plan dimension of structure	: 25 m X 20 m
Floor height	: 3 m
No of bay in X direction	: 6
No of bay in Y direction	: 6
Spacing in X direction	: 5 m
Spacing in Y direction	: 4 m
Beam sizes	: 230 mm X 350 mm
Column sizes	: 350 mm X 350 mm
Slab thickness	: 120 mm
Live Load	: 2 kN/m^2
Floor Finish Load	: 1.5 kN/m^2
Grade of concrete	: M 30
Steel of steel	: Fe 415
Modulus of elasticity of concrete	: 27386.13 MPa

Earthquake parameters

Type of structure	: RCC residential Building
Type of frame	: SMRF
Seismic zone	: IV
Seismic intensity	: 0.24
Importance factor	: 1.0
Response reduction factor	: 5 (SMRF)
Soil type	: Medium
Damping ratio	: 5%

3. Results and Discussion

3.1 Modal Analysis

As per Clause 7.7.5.2 of IS 1893 (Part I): 2016 [4] it is being stated that for a considered direction of earthquake shaking the summation of modal masses of all modes considered should be at least 90 percent of the total seismic mass. From **Table 2** it is observed that 90% participation is attained at fifth mode for Model 2, eleventh mode for Model 3, Model 4 and Model 5, which are step back buildings. And from **Table 3** it is observed that 90% participation is attained at eight mode for Model 6, eleventh for Model 7 and Model 9, fourteenth for Model 8. However, it is observed that 90 percent participation is attained at seventh mode for Model 1 the regular building on the plain ground. This confirms the energy dissipation capacity of regular building on plain ground is higher than the respective hill building. Further, it is observed that Model 2 building has higher energy dissipation capacity than other step back building. And Model 6 building has higher energy dissipation capacity than other step back set back buildings.

Table - 2: Comparison of cumulative modal participating mass ratios.

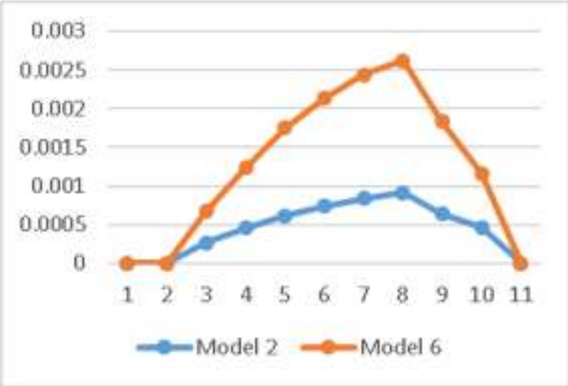
Mode	Model 1		Model 2		Model 3		Model 4		Model 5	
	Direction		Direction		Direction		Direction		Direction	
	X	Y	X	Y	X	Y	X	Y	X	Y
1	80.7	0.0	0.0	73.3	51.5	10.7	21.1	42.1	0.0	63.1
2	80.7	80.9	80.5	73.3	71.4	57.9	72.0	62.4	69.7	63.1
3	80.7	80.9	80.5	83.6	74.0	77.6	72.5	75.7	69.7	75.5
4	89.9	80.9	80.5	92.2	77.1	82.2	73.2	83.8	69.7	84.4
5	89.9	90.1	90.2	92.2	83.4	85.5	81.8	84.6	79.0	84.4
6	89.9	90.1	90.2	93.3	83.6	87.7	81.8	86.0	79.0	85.6
7	93.2	90.1	90.2	96.3	83.8	91.3	81.9	91.0	79.0	90.1
8	93.2	93.3	94.3	96.3	88.8	91.5	86.4	91.1	84.7	90.1
9	93.2	93.3	94.3	96.5	88.8	92.3	86.4	91.3	84.7	90.2
10	94.9	93.3	94.3	97.9	88.9	94.3	86.4	94.5	84.7	92.8
11	94.9	94.9	97.5	97.9	95.6	94.4	91.8	94.6	95.2	92.8
12	94.9	94.9	97.5	98.0	95.6	94.7	91.9	94.6	95.2	92.8

Table - 3: Comparison of cumulative modal participating mass ratios for step back set back of building.

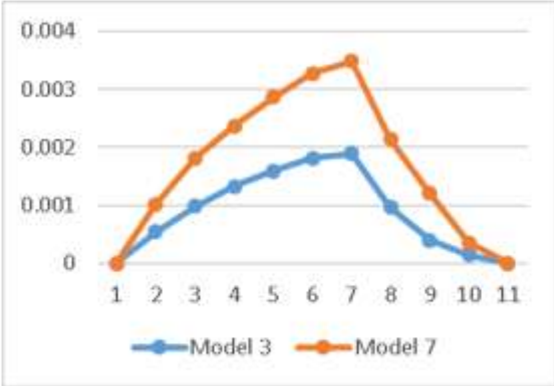
Mode	Model 6		Model 7		Model 8		Model 9	
	Direction		Direction		Direction		Direction	
	X	Y	X	Y	X	Y	X	Y
1	78.0	0.0	73.1	0.0	70.5	0.0	0.0	69.1
2	78.0	75.0	73.1	76.8	70.5	73.8	67.1	69.1
3	78.0	81.5	73.1	77.1	70.5	74.5	67.1	75.0
4	87.9	81.6	82.8	77.1	79.8	74.5	75.8	75.0
5	88.1	90.4	82.8	86.7	79.8	85.1	75.9	84.5
6	88.1	91.5	82.8	87.3	79.8	85.1	75.9	84.6
7	88.1	94.7	82.8	90.8	79.8	89.7	75.9	88.6
8	92.9	94.7	88.2	90.8	84.3	89.7	82.6	88.6
9	92.9	95.4	88.2	91.7	84.3	90.5	82.6	88.9
10	92.9	96.8	88.2	93.9	84.3	93.4	82.7	91.8
11	97.0	96.8	95.2	93.9	89.5	93.4	94.5	91.8
12	97.0	97.3	95.2	94.1	89.5	93.5	94.5	91.9
14	99.5	97.3	98.3	94.1	89.5	94.7	97.9	91.9

3.2 Story Drift Ratio

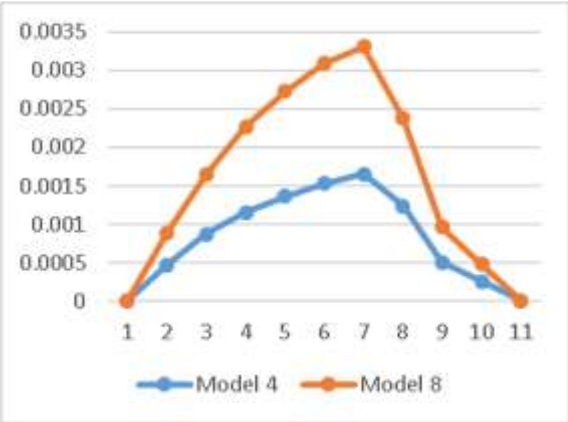
The comparison story drift ratios of set back and set back step back buildings presented in Figure 12, shows that set back step back buildings experience more story drift as compared to set back buildings.



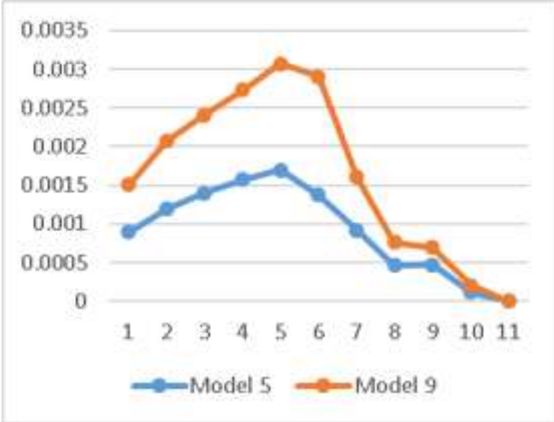
(a)



(b)



(c)

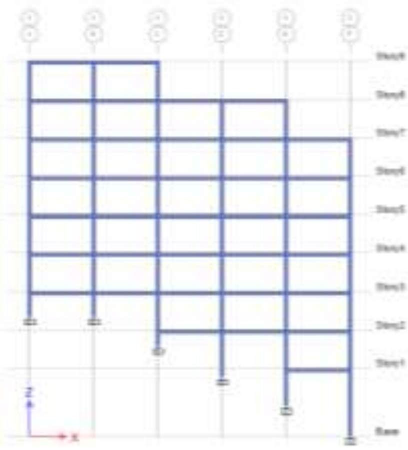


(d)

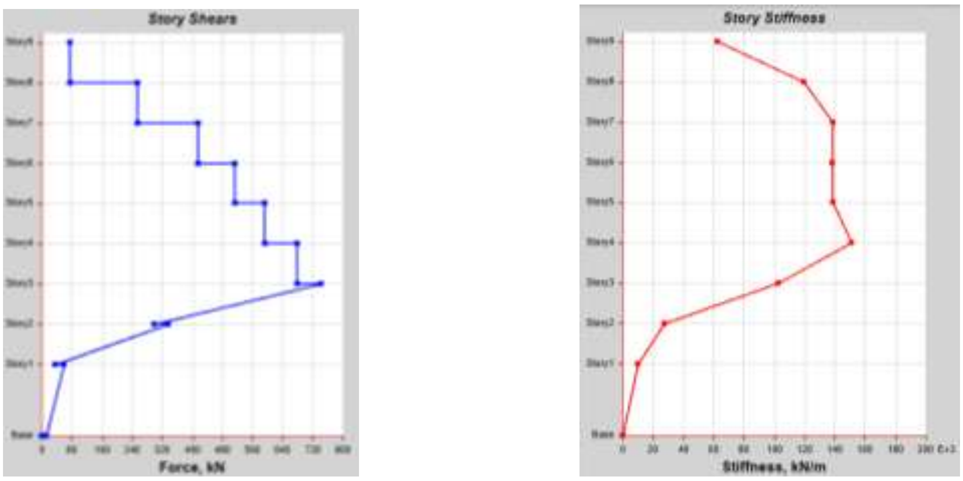
Chart - 1: Comparison story drift ratios of set back and set back step back buildings: **(a)** Buildings on 15° slope, **(b)** buildings on 20° slope, **(c)** buildings on 25° slope and **(d)** buildings on 30° slope.

3.3 Story Shear

As shown in **Fig - 13 (a)**, **(b)** and **(c),** at story level 3 there is abrupt change in story shear due the corresponding change in story stiffness. The short columns have great stiffness, hence attract large amount of shear force and bending moment. Thus, the section of these columns should be provided with more shear reinforcement to resist induced shear.



(a)

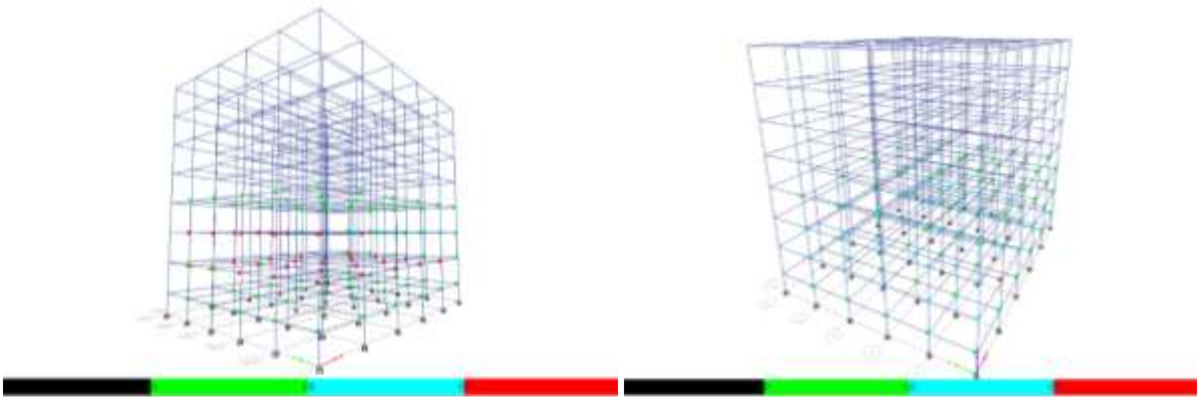


(b) **(c)**

Fig - 13 : (a) Model 8, **(b)** Story Shear plot and **(c)** Story Stiffness Plot.

3.4 Plastic Hinge Mechanism

Plastic hinges formation for the building mechanisms have been obtained at different displacement levels. The hinge patterns are plotted at different levels in **Fig - 14 (a)** Plastic hinges formation starts with beam ends and base columns of lower stories, then propagates to upper stories and continue with yielding of interior intermediate columns in the upper stories. The hinges highlighted with (CP) collapse prevention level those members are revised. Hinge pattern of revised design is as shown in **Fig - 14 (b)**.



(a) **(b)**

Fig - 14 : (a) Hinge pattern after design revision and **(b)** Hinge pattern after design revision.

3. CONCLUSIONS

The performance of buildings resting on sloping ground differ significantly with building resting on plain ground. Some inferences are mentioned below:

1. From the cumulative modal mass participation ratio it is concluded that, as the slope angle increases energy dissipation capacity decreases.
2. And dissipation capacity of building resting building plain ground is higher than the hill buildings.
3. Set back step back buildings experience more story drift as compared to set back buildings.
4. Short columns attract large amount of shear force, therefore should be provided with sufficient shear reinforcement.
5. Plastic hinges are initially formed in beams, hence collapse occurs through the beam mechanism, which localize the failure and hence leads to less destruction.
6. Hinge mechanism is formed in short columns earlier as the slope angle increases.

The formation of plastic hinges in beams first represents weak beam and strong column mechanism. Nonlinear static analysis is sufficient to highlight the seismic vulnerability of the buildings and computationally economical.

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